US Army Corps
of Engineers
Waterways Experiment
Station

Water Operations Technical Support

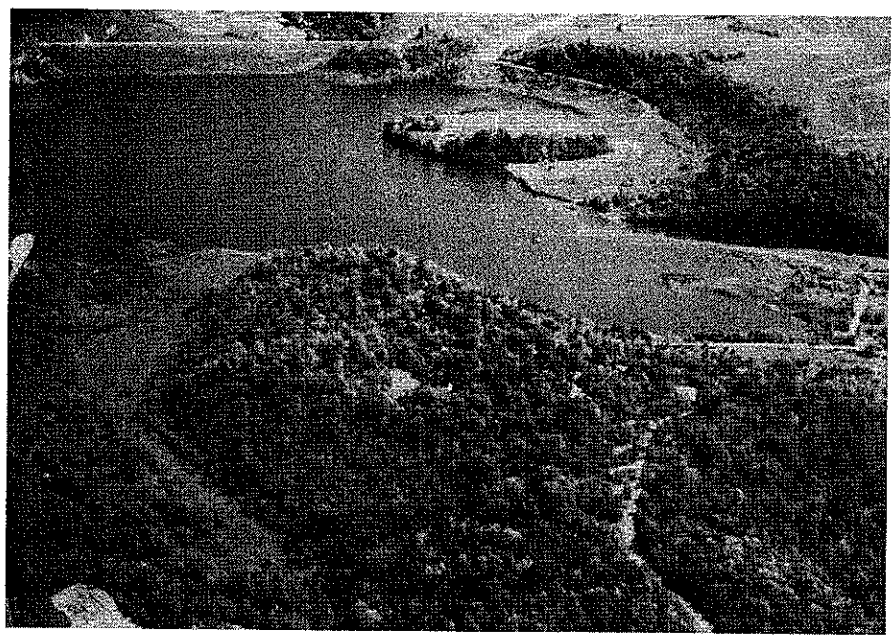
Vol E-92-5 November 1992

Effects of sediment oxygen demand on dissolved oxygen concentrations and nutrient release

by Cynthia B. Price

The oxygen status of the water column is an important parameter in determining and predicting water quality. Sediment oxygen demand (SOD) (the rate of oxygen removal from the water column) is usually the largest sink for dissolved oxygen (DO) from the water column. SOD encompasses oxygen consumed by decomposition of settled organic matter and other biological activity in sediment, and chemical oxidation of reduced species, including Fe^{2+}, Mn^{2+}, and S^{2-} (Wang 1981).

Dissolved oxygen concentrations and SOD-regulated processes occurring at the sediment-water interface regulate the movement of reduced chemical species from the sediment surface into the overlying water (Brannon and others 1983 and Gunnison, Chen, and Brannon 1983). These interactions can then contribute to poor quality of surface water. For example, microbial degradation of organic matter in the sediment can result in DO depletion and the eventual development of anoxic conditions in the overlying water column. Anoxic conditions can result in the release of and accumulation of ammonium-nitrogen, phosphorus, reduced iron and manganese, and sulfide from the sediment. Perturbation of the sediment surface may accelerate this process by increasing the movement of oxygen-demanding reduced species from the sediment into the overlying water (James and others 1992). For these reasons, DO levels and SOD-regulated processes can have a major impact on the operation of U.S. Army Corps of Engineers water resource projects, including reservoirs, navigation projects, and water-control structures.



Sediment samples currently being tested at the Waterways Experiment Station were obtained from Eau Galle Lake

Predicting the effects of Corps water resource projects on water quality has been difficult due to the lack of a standard method to accurately measure, quantify, evaluate, and predict SOD. This has necessitated the development of a Corps-wide standard procedure to

analyze SOD in riverine, lacustrine, and estuarine environments.

Initial investigations by the U.S. Army Engineer Waterways Experiment Station (WES) consisted of a literature review and workshop to determine the state of the art of SOD research (Cerco, Gunnison, and Price 1991 and Price 1991). WES is currently conducting laboratory studies interactively with model development to accurately measure, evaluate, and predict SOD for Corps water resources projects. The objective of the laboratory investigations is to determine the SOD-regulated processes of DO depletion and nutrient release from sediments.

Laboratory investigations

Test tubes

Studies to assess nutrient release and DO consumption from Brown's Lake sediment were determined in 50-milliliter test tubes. Dissolved oxygen, ammonium-nitrogen, orthophosphate-phosphorus, nitrate-nitrogen, and total organic carbon (TOC) concentrations were measured over 36 days. Two separate studies were conducted. The first study used Brown's Lake sediment amended with 1 percent organic matter, and the second study included two additional sets of tubes containing sediment amended with 5 and 10 percent organic matter. The sediment was then covered with water and the tubes sealed to produce anaerobic conditions.

In the first study, DO levels decreased, exhibiting an initial rapid decline and reaching a steady state as oxygen levels fell below 2 milligrams per liter (mg/L). Similar findings were reported by Wang (1981), who observed sharp initial decreases of residual oxygen followed by a tapering off once DO levels fell below 2 mg/L. Dissolved oxygen depletion was accompanied by subsequent increases in both ammonium and orthophosphate concentrations (Figure 1).

Dissolved oxygen levels in the water above sediment containing high organic matter exhibited much the same behavior (Figure 2). No significant differences were observed in DO depletion or nutrient release among the three organic matter levels ($p < 0.01$) (Figure 3). These results suggest that the rate of oxygen supply to the sediment limited the utilization of the substrates. Phosphorus concentrations initially increased followed by a decline to a steady state. TOC concentrations also increased and then gradually decreased to a steady state.

Columns

Twenty-liter plexiglass columns were used to determine DO depletion in the water column and nutrient release from bedded lacustrine and estuarine sediments. The sediments included Brown's Lake, Rathbun Lake, and Chesapeake Bay. Three separate column studies were conducted with three replicates for each sediment. Columns were loaded to a depth of 15 centimeters with sediment, covered with 15.7 liters of water, and sealed from atmospheric contact (Figure 4). Measurements for DO and nutrients were taken weekly for 30-day periods. All three sediments tested exhibited similar trends in DO depletion, nutrient releases, and TOC concentrations. Figure 5 presents data obtained using Chesapeake Bay sediment.

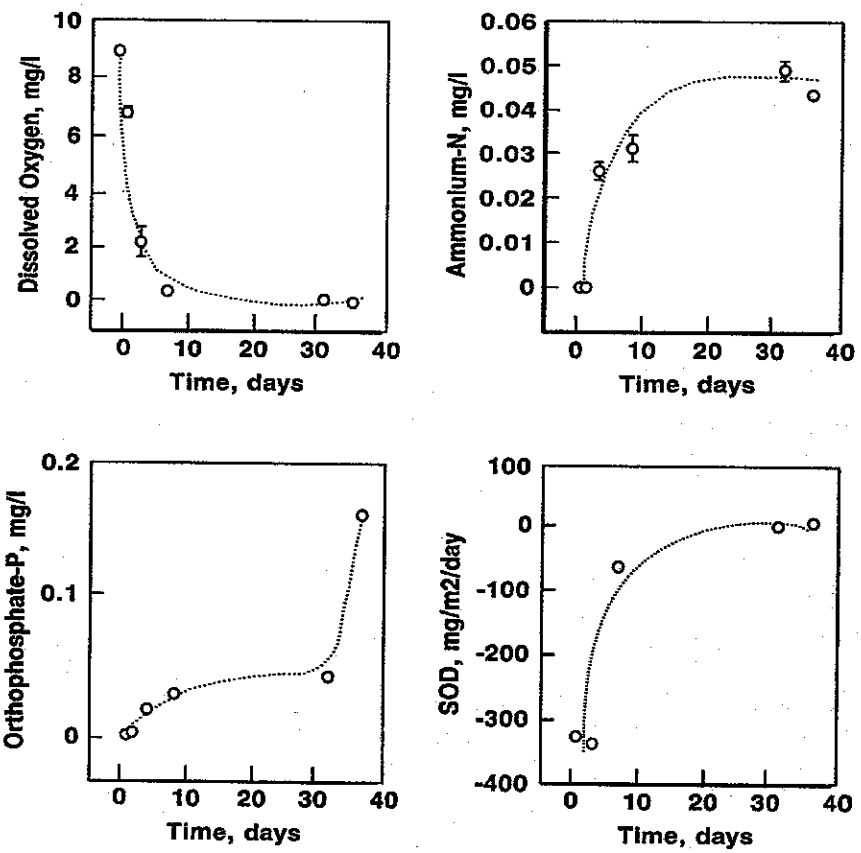


Figure 1. Dissolved oxygen and nutrient concentrations measured in the overlying water of a lacustrine sediment containing 1 percent additional organic matter

Dissolved oxygen levels exhibited similar behavior in the columns as in the test tubes, with an initial rapid decline to a steady state. Ammonium levels displayed initial increases and then reached steady state, possibly a result of limited organic nitrogen levels in the sediment. In the absence of oxygen, organic nitrogen is broken down to ammonium which accumulates as ammonium-nitrogen in the sediment interstitial water (Koike and Hattori 1978). Orthophosphate-phosphorus concentrations initially increased and then decreased to steady state. Nitrate-nitrogen concentrations initially increased followed by a sharp decline which corresponded to a decrease in DO to below 2 mg/L. TOC levels initially increased, followed by a gradual decline.

Discussion

The flux of oxygen-demanding substituents from bottom sediments into the overlying water column can give information about potential SOD. Test tubes and columns were both used to simulate bedded sediments with an overlying water column. The systems were allowed to develop anaerobic conditions naturally, and DO depletion and nutrient release were measured over time. Test tubes were used initially to rapidly develop anaerobic conditions, avoid replacement of water removed through sampling, and compare the SOD rates of sediments containing different concentrations of organic matter.

Although test tube studies were successful, testing was shifted to larger columns; the larger volume of water allowed replacement of water sampled without creating significant changes in the chemical composition of the water column.

Dissolved oxygen concentrations followed the same trend in

Physical Characteristics of Sediments Used in the Test Tube and Column Studies

Sediment	Location	Fraction Solids	Organic Matter percent	Particle Size Sand percent	Silt percent	Clay percent
Brown's Lake	Mississippi	0.4513	1.82	5	70	25
Rathbun Lake	Iowa	0.6505	7.33	88	8	4
Chesapeake Bay	Maryland	0.7496	1.53	52	38	10

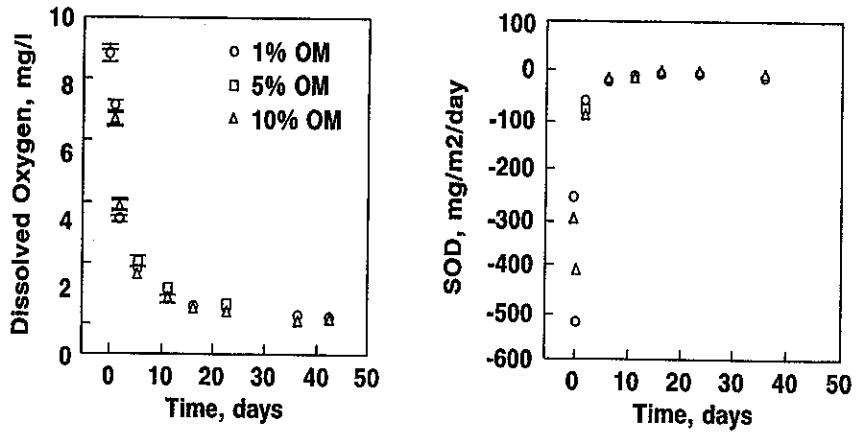


Figure 2. Dissolved oxygen and nutrient concentrations in the overlying water of a lacustrine sediment amended with three different levels of organic matter

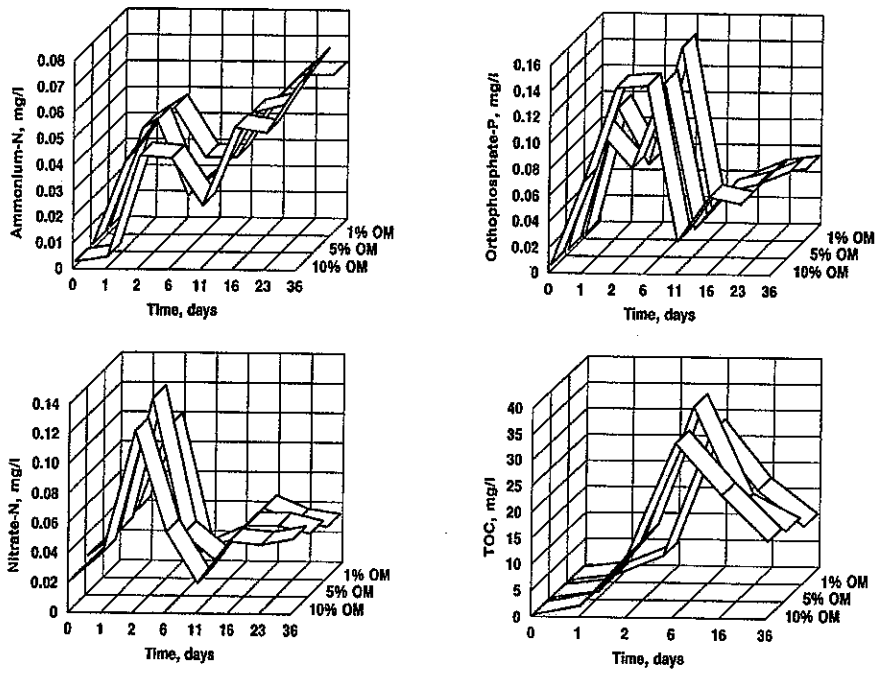


Figure 3. Nutrient and TOC concentrations released from a lacustrine sediment amended with three different levels of organic matter

both the test tubes and columns. A decrease in DO depletion rate occurred when DO levels fell below 2 mg/L. Decomposition of organic matter will readily remove oxygen from waters not having a continuous source of reaeration.

Plant nutrients, including inorganic phosphorus and inorganic nitrogen, are released by decomposition processes acting in flooded soils and sediments (Koike and Hattori 1978 and Patrick 1990). Anaerobic conditions generally favor release of ammonium-nitrogen, orthophosphate-phosphorus, methane, and sulfide-sulfur, while aerobic conditions favor the release of nitrate-nitrogen and sulfate-sulfur. However, orthophosphate-phosphorus can coprecipitate with iron sulfide. This is an important process in marine environments, but often not as important in freshwater systems. Ammonium-nitrogen levels increased over time in both test tubes and columns as conditions became more anoxic. Ammonium concentrations did reach steady state, a possible result of limited sediment organic nitrogen levels.

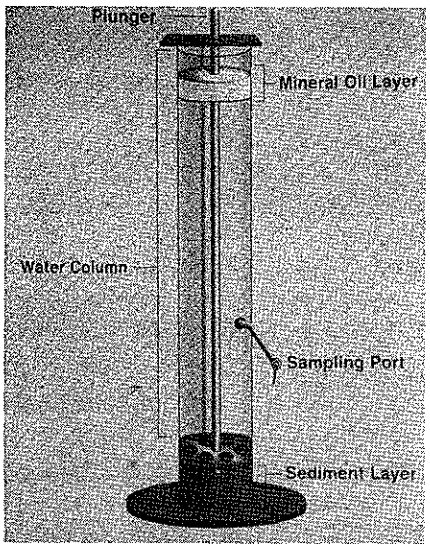


Figure 4. Plexiglass column used to determine SOD and nutrient release from Brown's Lake, Rathbun Lake, and Chesapeake Bay sediments

Increased orthophosphate-phosphorus concentrations in both the columns and tubes were followed by a gradual decline possibly due to formation of aluminum or calcium phosphate precipitates. Nitrate-nitrogen concentrations initially increased in the columns and tubes, but began to decline when DO levels fell below approximately 1.5 mg/L. When nitrate is formed in the aerobic sediment layer, it can diffuse into the water column or into the anaerobic sediment layer. However, net diffusion is downward where the nitrate undergoes denitrification (Patrick 1990). Total organic carbon concentrations increased in all tests, followed by a decline which corresponded to a decrease in the DO depletion rate. Gunnison (1983) found that the concentration of soluble TOC in the water column strongly correlated with a decrease in the DO depletion rate. TOC tends to accumulate under anaerobic conditions, where it is not utilized as readily as under aerobic conditions. Total inorganic carbon

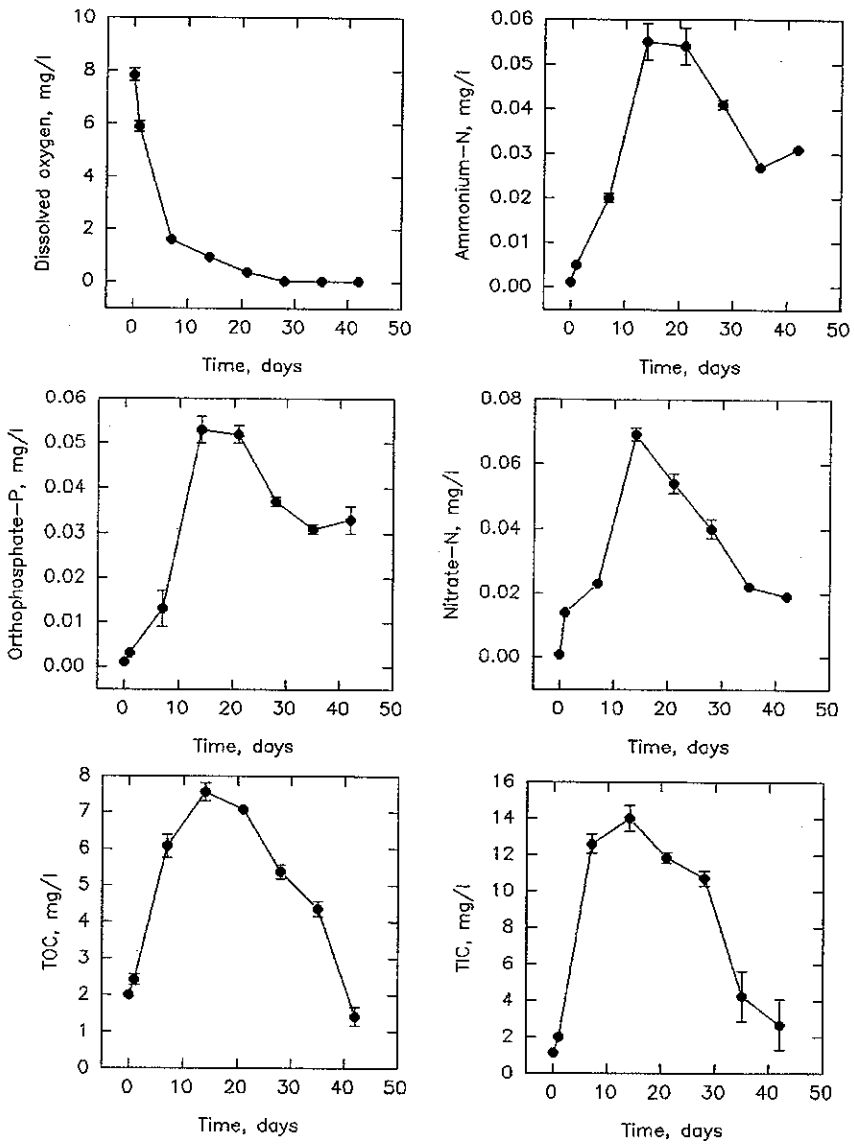


Figure 5. Dissolved oxygen and nutrient concentrations measured in the overlying water of an estuarine sediment

(TIC), by contrast, often initially accumulates under anaerobic conditions, and then decreases as the release of soluble reduced metals is followed by the formation of insoluble metal carbonates.

Model development

A predictive model of sediment oxygen demand and sediment-water nutrient flux is available for use in this study. The model was developed for Chesapeake Bay and extensively verified in that application. One purpose of the previously described laboratory studies is to develop a data base for testing the model against sediments drawn from different environments. The model-data comparisons will direct improvements in the model which will be tested in further experiments.

One improvement required in the model is evident without laboratory experimentation. Iron and manganese release must be included for the model to be effective in Corps reservoir projects. Implementation of iron and manganese is underway. Performance of the model in this regard will initially be demonstrated against existing data bases from various water resources projects.

Conclusions

Initial studies using test tubes and columns have confirmed that dissolved oxygen levels and nutrient releases are directly related to SOD processes. These investigations have indicated a need to quantify several additional parameters to further relate sediment properties to SOD exertion. These include determination of labile and refractory organic carbon and an estimation of microbial biomass. Progress has been made on evaluating a broad range of characteristically different sediments. Further studies to include additional sediments and biochemical parameters are needed to better understand the effects of SOD on nutrient release in different aquatic environments.

WES is currently conducting column studies with additional sediments to determine the effects of sediment aging on SOD. Field studies using in-situ measurements will be undertaken next year to correlate with laboratory data.

For further information, contact Ms. Cynthia Price at (601) 634-3621, Dr. Douglas Gunnison at (601) 634-3873, or Dr. Carl Cerco at (601) 634-4207.

References

Brannon, J. M., Gunnison, D., Smart, R. M., and Chen, R. L. 1983. "Effects of Added Organic Matter on Iron and Manganese Redox Systems in Sediment," *Geomicrobiology Journal*, Vol 3, pp 319-341.

Cerco, C., Gunnison, D., and Price, C. B. 1991. "Proceedings, US Army Corps of Engineers Workshop on Sediment Oxygen Demand, Providence, Rhode Island, 21-22 August 1990," Miscellaneous Paper W-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Gunnison, D., Chen, R. L., and Brannon, J. M. 1983. "Relationships of Materials in Flooded Soils and Sediments to the Water Quality of Reservoirs - I. Oxygen Consumption Rates," *Water Research*, Vol 17, pp 1,609-1,617.

James, W. F., Eaking, H. L., Gunnison, D., and Barko, J. W. 1992. "Sediment-Overlying Water Relationships Affecting Wintertime Dissolved Oxygen Conditions in the Big Eau Pleine Reservoir, Wisconsin," Technical Report W-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

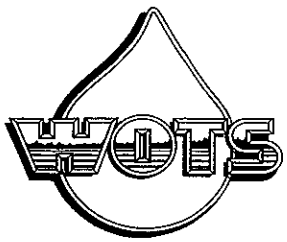
Koike, I., and Hattori, A. 1978. "Denitrification and Ammonia Formation in Anaerobic Coastal Sediments," *Applied and Environmental Microbiology*, Vol 35, No. 2, pp 278-282.

Patrick, W. H. 1990. "Microbial Reactions of Nitrogen and Phosphorus in Wetlands," Symposium on Wetlands and Water Quality, Wageningen, Netherlands.

Price, C. B. 1991. "Sediment Oxygen Demand and Its Effects on Water Quality," *Water Operations Technical Support*, Vol E-91-2, pp 5-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wang, W. 1981. "Kinetics of Sediment Oxygen Demand," *Water Research*, Vol 15, pp 475-482.

***Cynthia Price** is a physical scientist with the Ecosystem Research and Simulation Division (ERSD), Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station (WES). Cynthia has a Bachelor of Science degree in wildlife biology from Texas A&M University and has completed several course requirements for a Master of Science degree in chemistry. Her current research interests include water quality, sediment-water interactions, and leachates.*



This issue reports on laboratory studies being interactively conducted with model development to accurately measure, evaluate, and predict sediment oxygen demand (SOD) for Corps water resources projects. The laboratory investigations are being performed to determine the SOD-regulated processes of dissolved oxygen depletion and nutrient release from sediments.

WATER QUALITY RESEARCH PROGRAM

This bulletin is published in accordance with AR 25-30. It has been prepared and distributed as one of the information dissemination functions of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from the Water Quality Research Program (WQRP) can be rapidly and widely disseminated to Corps District and Division offices as well as other Federal agencies, state agencies, universities, research institutes, corporations, and individuals. Contributions of any type are solicited from all sources and will be considered for publication as long as they are relevant to the objectives of WQRP, i.e., to provide new or improved technology to solve selected environmental quality problems associated with Civil Works activities of the Corps of Engineers in a manner compatible with authorized project purposes. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Decell, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call AC 601/634-3494.

ROBERT W. WHALIN, PhD, PE
Director

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199

OFFICIAL BUSINESS
CEWES-EV-I

BULK RATE
U.S. POSTAGE PAID
Vicksburg, MS
Permit No. 85